Cost-Benefit Analysis Methodology: Install Commercially Compliant Engines on National Security Exempted Vessels?

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The Environmental Protection Agency (EPA) national security exemption (NSE) status can be applied to new and existing U.S. flagged vessels having a national defense mission and meeting associated criteria. Benefits of installing noncompliant marine engines on NSE vessels may include preserving a vessel class' primary defense mission capability and engine configuration control. The drawback is increased emissions. An objective and versatile methodology framework was developed to quantify the cost-benefit tradeoff for NSE vessels, vehicles, and equipment. The parametric-based comparison of one-time and ongoing costs with monetized health benefit (utilized in conventional regulatory impact analyses) satisfactorily encompasses the fundamentals of environmental health risk and can be applied to all mobile and stationary equipment types.

INTRODUCTION

Commercial diesel engines on new and existing U.S. flagged or registered vessels (or equipment in general) must comply with Environmental Protection Agency (EPA) exhaust emission regulations. However, EPA includes national security exemption (NSE) provisions in all legislated engine emission regulations in order to exempt engines installed in equipment used for national security and not in commercial service. By applying NSEs, military services and other government agencies can choose to procure engines that are not in commercial compliance. That option is offered by EPA and applied by the Services in cases where commercially compliant engines might compromise the required national security mission and when alternative noncompliant engine models are available.

Both costs and benefits accompany each acquisition-related engine commercial compliance decision for vessels or, more broadly, any mobile and stationary equipment meeting the NSE criteria. Although a great number of such decisions are made annually, there is no standardized methodology that can be applied across the spectrum of engine types and the equipment for which those engines are being specified.

The purpose of this paper is to present an objective, cost-benefit analysis methodology framework that is versatile and user friendly, equally acceptable and compelling to both acquisition officers and regulators. This is achieved by utilizing the monetized health benefit (MHB) concept, which is employed as a benchmark in EPA Regulatory Impact Analyses (RIAs). EPA employs MHB to quantify the value of particulate matter (PM) reduction and compare that with projected increases in procurement, installation, and operating costs to meet commercial-compliance regulations.

This paper does not seek to justify the EPA MHB approach, but explains the fundamentals and describes how the MHB concept can be utilized to quantify certain commercial compliance benefits. Services and agencies having the NSE option can apply the methodology framework to weigh costs and benefits of installing commercially compliant engines.

If a defined methodology gains acceptance within the defense and national security community, its increasing use would significantly strengthen environmental stewardship and mitigate accompanying health impacts – particularly for operators. The availability of a standardized tool enables cost efficiencies by streamlining the decision process to determine selection of either commercially compliant or noncompliant engines for NSE-eligible vessels, vehicles, and equipment.

BACKGROUND

The military services and government agencies responsible for national security are required to fulfill their primary missions while also exercising environmental stewardship. Working to achieve both objectives during the pre-systems and systems acquisition phases can be a significant challenge. The following explanation of marine regulations will assist managers of other equipment types to assess the applicability of this methodology.

Problem: Military Equipment Environmental Compliance

The Navy is required to comply with Clean Air Act (CAA) requirements and related federal, state, and local regulations "in the same manner and to the same extent as any nongovernmental entity" (OPNAVINST 2014). However, EPA's NSE provisions afford vessels or equipment with combat features to contain engines not in commercial compliance and operate on fuel not in commercial compliance (EPA 1999).

From strictly an environmental standpoint commercial compliance is preferred. However, if compliance imposes unacceptable mission limitations, affordability, or delays, these factors may provide justification to apply or request NSEs. No equivalent NSE exists for land installation conformity requirements and the vessels and equipment dedicated or home ported to those activities.

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14. ABSTRACT
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Universal Objectives of acquisition officers, installations, and users include emission reductions to reduce air quality impacts and personnel exposure to pollutants. In the marine sector, compliance is generally sought to meet the following EPA and International Maritime Organization (IMO) requirements:

1. New engine regulations and maintenance (Table 1);
2. Documentation (Table 2);
3. EPA existing engine regulations – encompassing rebuild, remanufacture, and replacement requirements; and
4. Fuel regulations (EPA 1999, EPA 2008).

Table 1. Marine diesel engine regulation tiers and implementation dates

EPA			IMO	
Tier 1	1999-2004		Tier I	2000
Tier 2	2004-2007		Tier II	2011
Tier 3	2009-2018			
Tier 4	2014-2017		Tier III*	2016

*NOTE: Within Emission Control Areas [ECAs] only

Table 2. Summary of commercial compliance certification and documentation requirements

EPA (compliance required for all vessels that are U.S. flagged or registered):

- Issues Certificate of Compliance (CoC) issued to OEM for each certified engine; OEM provides to purchaser
- Issues Engine Air Pollution Prevention (EIAPP) Certificate for each engine rated >130 kW
- In-service inspection

IMO (compliance required for all vessels that are operating internationally and/or powered by EPA Category 3 [≥30 L/cylinder] engines):

- Engine Air Pollution Prevention (EIAPP) certification for each engine rated >130 kW
- International Air Pollution Prevention (IAPP) certification for every vessel >400 GRT
- Requires OEM Technical File (compliance verification information)
- Requires Record Book of Engine Parameters (documentation of component and setting changes that could impact NO_x emissions)

USCG:

- Certifies IMO Annex VI vessel compliance, if >400 GRT with International Air Pollution Prevention (IAPP) certificate and IAPP Supplement
- In-service enforcement

Classification societies:

- Routine surveys

For a new vessel to be "commercially compliant" with EPA diesel engine emission regulations, each engine dedicated to that vessel system must be commercially compliant. All the installed marine engines, portable engines, and the ship's boat engines are encompassed (Thomas, personal communication [pers. com.]).

Commercial compliance includes new engine certification, maintenance, and remanufacture requirements. All certification documents should be available for inspection (Thomas, pers. com.). The responsibility to inspect and enforce compliance has been assigned to EPA and the U.S. Coast Guard (USCG).

Engines on ships flagged or registered in the United States must comply with EPA regulations. U.S. ships operating internationally and/or powered by Category 3 engines must also comply with IMO regulations.

For valid compliance, every operating marine engine not eligible for exemption must possess an Engine International Air Pollution Prevention (EIAPP) for IMO compliance, a Certificate of Conformity for EPA compliance (Table 2), or be labeled with the relevant exemption. IMO and EPA engine exemptions are not identical. An IMO exemption does not imply EPA exemption and vice versa. Classification societies responsible for surveying vessels, do not keep certification documents on file and the EPA on-line data certification base is not complete.

Unique Military Constraints include limitations of size and weight, tolerance to military specification (MilSpec) fuels and lubricating oil, logistic challenges for introduction of new fluids, hurdles posed by unique operating conditions and mission requirements, and management of configuration control for a vessel class (Schihl 2009).

Provisions: Regulatory Emission Reduction Program

EPA's program for emissions regulation is intended to yield very significant reductions over a 40-year time period. This is to be achieved by equitably sharing the responsibility between source types. The focus has been on particulate matter (PM), nitrogen oxides (NO_x), and hydrocarbons (HC), although carbon monoxide (CO) is also regulated. Sulfur oxides (SO_x) are not regulated, but controlled through regulating fuel sulfur limits.

The program was prioritized by addressing the sectors with the largest populations of engines and where engine turnover is most frequent. Targeting useful life and comprehensive emissions affords the most cost-effective opportunities for technology development, impact, and reductions. EPA has now regulated all mobile transportation and stationary sources. The marine sector was fully addressed last. Seeking regulatory globalization and harmonization between source types, EPA has legislated what it considered manageable emission limit steps according to source type. Through international cooperation, EPA has also sought to reduce a global patchwork of regulations and ratchet down emission limits over time.

EPA's program coordinates strategy to control emissions from marine vessels through both national (under CAA authority) and international regulation. By international treaty the U.S. has accepted the IMO International Convention for the Prevention of Pollution from Ships, 1973/78 (MARPOL) Annex VI. The designation of Emission Control Area (ECA) now applies to all U.S. coasts. Within ECAs, all vessels, regardless of flag, are required to meet the most stringent IMO Annex VI engine and marine fuel sulfur requirements.

New engine EPA standards increase in stringency with increasing regulation "tier," starting with Tier 1 and advancing to Tier 4 (applicable to engines rated above 600 kilowatt [kW])

(EPA 2008). The Tier 4 regulation assumes the application of advanced catalyst-based aftertreatment (AT) technology and an enabling 15 parts per million (ppm) sulfur-limited ultra-low sulfur diesel fuel (ULSD). Existing marine diesel engines rated above 600 kW are also required to meet "remanufacture" (encompassing maintenance, repair, and overhaul) standards.

Regulations and Emission Control Technologies have advanced in tandem. The more stringent regulations require controls based on more interventionist strategies. In-cylinder and on-engine controls were generally applied first by engine original equipment manufacturers (OEMs) followed by higher installation- and operating-cost exhaust AT.

Regulations and engine design changes to achieve the regulated limits have progressed as follows (EPA 2009):

- EPA Tier 1 NO_x and IMO Tier I standards deliver ~20% reductions over uncontrolled levels. The standards were met with modified engine timing, higher compression ratios, and optimized turbocharging and fuel injection.
- EPA Tier 2 NO_x and IMO Tier II standards require an additional ~20% reduction from Tier 1. EPA imposed a PM standard; IMO achieved PM emissions benefits by regulating marine fuel sulfur. These standards were met using advanced integration of modified engine timing, optimized turbocharging, higher compression ratios, engine cooling, and advanced computer controls and optimized fuel injection (electronic and/or common rail), including increased injection pressure, low sac volume injectors, and rate shaping fuel delivery during injection.
- EPA Tiers 3 and 4 NO_x and IMO Tier III deliver a final ~80% reduction from the prior standard. EPA reduced the PM limit and IMO reduced marine fuel sulfur limits.
  - EPA Tier 3 applies to engines rated below 3700 kW and can be met by further application of the in-engine and in-cylinder technologies applied to meet Tier 2. Additional technologies utilized include multiple tailored injection events, swirl-enhancing inlet ports, reentrant piston bowls, and exhaust gas recirculation (EGR). OEMs apply in-cylinder technologies prior to increased turbocharger configuration complexity, further cooling of intake air and/or EGR, or any type of exhaust AT.
  - EPA Tier 4 applies to engines rated above 600 kW and will likely require high-efficiency controls that utilize advanced AT. Ordered by descending broad favorability, the AT technologies follow:

    1. Selective catalytic reduction (SCR)
    2. Diesel particulate filter (DPF)
       – electrically regenerated active (ERADPF)
       – catalyzed (CDPF)
       – catalyzed regenerated active (CRADPF)
    3. Diesel oxidation catalyst (DOC)
    4. Closed loop exhaust temperature control
    5. Lean NO_x trap (LNT)
    6. Exhaust gas recirculation (EGR)
    7. SO_x scrubber (SCB)

Currently, at least one OEM has announced it will not utilize SCR to achieve Tier 4 because of the required volume, weight, complexity, and cost. If breakthrough combustion-cycle-modifying technologies are developed for highway heavy-duty diesel (HDD) engines, broad application of marine engine AT may be avoided.

Exemptions, provided by EPA, can be applied for different engine applications, including the NSEs made available to the defense and security community.

Automatic NSEs may be applied to Navy vessel engines that meet the following criteria: "substantial features ordinarily associated with military combat, such as armor, permanently affixed weaponry, specialized electronic warfare systems, unique stealth performance requirements, and/or unique combat maneuverability requirements and which will be owned and/or used by an agency of the federal government with the responsibility for national defense" (EPA 1999).

NSEs may also be requested for justifiable installation of noncompliant engines in vessels or equipment not meeting the automatic NSE criteria (EPA 1999). EPA also provides a fuel NSE directed toward deployable equipment (EPA 2004).

Deficiency: Procedure to Assess and Select Commercial Compliance or Exemption

EPA has primarily left the use of NSEs up to the discretion of the military services and other security agencies. Other than identifying NSE eligibility criteria, EPA provides no broad application requirements or guidance. The community of government organizations responsible for national security needs a standardized process for assessing the costs and benefits of procuring commercially compliant engines and compliance-enabling commercial-off-the-shelf (COTS) or edge-of-the-shelf (EOTS) technologies that can be integrated into new multiyear-procurement and existing vessels and equipment.

PROPOSED METHODOLOGY FRAMEWORK

Engine compliance decisions require an objective assessment of commercially compliant engines or the application of selected commercial-compliance emission control technologies to a particular configuration newbuild vessel or new equipment. This assessment should be conducted at the beginning of each multiyear-procurement build or production period. However, commercial compliance may need to be evaluated in the middle of a procurement build or production period if compliance had not been previously considered in an objective manner. At the time of a vessel reengining or overhaul (termed "remanufacture" by EPA), an assessment should also be routinely performed.

In these assessments, the impact of each candidate compliant engine or control technology is measured according to the increase in cost for the compliant engine and/or hardware (qualification, acquisition, and installation), interfacing systems' modification, and life cycle costs. A comparison of these costs with acquired commercial-compliance benefits may then be conducted by referencing quantified EPA RIA MHB estimates.

EPA uses a consistent methodology to estimate MHB for all their RIAs. If air quality (AQ) data is available, their reference

scenario (baseline) is compared with a control scenario (policy scenario with the prospective rule in place). The AQ change is used to quantify and monetize the avoided health impacts associated with that change. If AQ data is not available, source apportionment MHB per ton (MHBPT) values are multiplied by projected changes in emissions mass (Davidson, pers. com.).

The EPA MHBPT values referenced in this paper are derived from inventory and epidemiological data, associated with health benefit gains from PM exposure reduction alone. This PM includes directly emitted $PM_{2.5}$ and its precursors (SO_2 and NO_x). MHBPT does not include associated benefits from other criteria pollutants such as ozone, SO_2, or NO_2. Like all AQ impact analyses, the benefits-per-ton method also does not monetize all potential health and welfare effects associated with PM reductions (EPA 2008, EPA 2012).

In this paper's methodology framework no variation from EPA's PM MHBPT estimates is proposed. In their current form, these estimates provide a basis from which the beneficial PM-related health impacts of commercial compliance may be quantified. Since the EPA approach continues to be refined, application of this methodology framework may provide data that could further improve EPA's analysis and modeling.

MHBPT is fundamentally a valuation of health risk reductions resulting from improved AQ. When the risk of regulated pollutants' contribution to serious public health problems is reduced, premature mortality and morbidity (respiratory and cardiovascular disease, asthma, acute respiratory symptoms, and chronic bronchitis) will likewise be reduced (EPA 2012).

EPA determines PM MHBPT values by enlisting source apportionment photochemical modeling to predict ambient concentrations of primary $PM_{2.5}$, particulate nitrate, and particulate sulfate that are attributable to 17 emission source sectors in the Continental U.S. The sectors of primary interest for NSE vessels, vehicles, and equipment include the following: onroad mobile sources; nonroad mobile sources; aircraft, locomotives, and marine vessels; and ocean-going vessels. The health impacts and economic benefits for each sector, attributable to ambient concentrations of the three types of PM, are then estimated using the environmental Benefits Mapping and Analysis Program (BenMAP). Finally, the health impacts attributable to each type of particulate and the monetary value of each related set of impacts are divided by the associated precursor emissions (primary $PM_{2.5}$ benefits divided by $PM_{2.5}$ emissions, sulfate benefits are divided by SO_2 emissions, and nitrate benefits are divided by NO_x emissions) (EPA 2013). Further detail on EPA's derivation process, assumptions, and uncertainties are provided in the "MHB" section of the paper.

Diesel engine PM is classified by EPA and the U.S. National Toxicology Program as mutagenic and a probable human carcinogen (EPA 2008). The California Air Resource Board (CARB) and the International Agency for Research on Cancer (IARC) (World Health Organization [WHO]) classify it as a known carcinogen (SCAQMD 2005, USNTP 2011, IARC 2012). Children, the elderly, and individuals with heart and lung diseases, are most at risk (EPA 2008).

Sailors and operators who regularly inhale pollutants from the exhaust plumes under certain operational and wind conditions (whether on the main deck or a more constricted well deck) may complain of acrid smell and stinging eyes. However, the associated longer-term health effects pose greater health risks.

This paper's methodology framework prescribes that the engine or ship emission control modification cost rate be compared to the MHB rate to determine payback period and return on investment (ROI) (Thomas, pers. com., EPA Jan 2013, Fann 2012). The Government's primary interest in a cost-benefit analysis of a prospective investment is the total cost savings produced by that investment. The related form of ROI used in this paper is a measure of the commercial compliance investment return in dollars. For an assumed vessel or equipment lifetime, the added nonrecurring and recurring engine costs (qualification, build and life cycle support costs) are subtracted from the added value of that investment (Eq. 1).

$$MHB_{tot} - TC_{tot} = ROI_{life} \tag{1}$$

Where MHB_{tot} ($CY) is calculated based on pollutant reductions, according to specific calendar year dollars and is the total cumulative MHB for the life of the vessel or equipment, TC_{tot} ($CY) is the total cumulative nonrecurring and recurring costs, and ROI_{life} ($CY) is the cumulative return minus cumulative costs for the investment period (equal to the assumed useful life of the vessel or equipment).

The assessment methodology framework process includes addressing the following primary elements (Fig. 1).

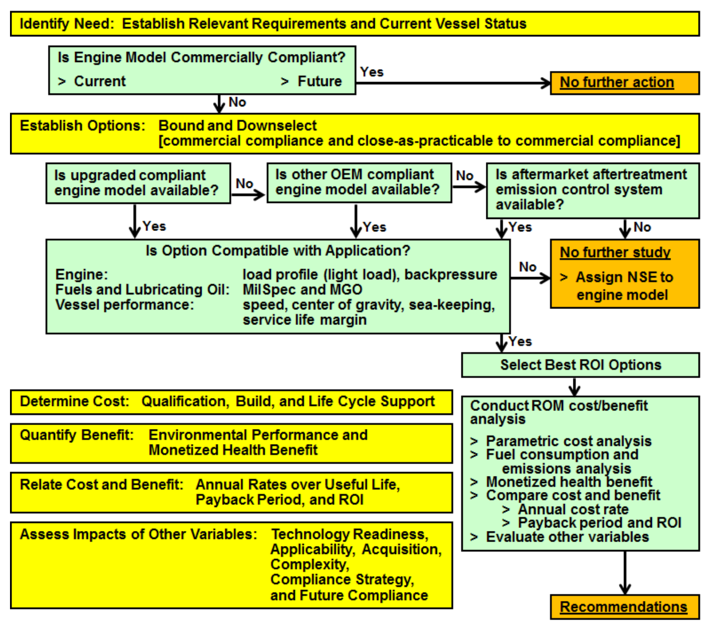

Fig. 1 Methodology framework and decision process flow chart

Need. Identification of commercial compliance need may be determined by comparing regulatory requirements with newbuild specifications or current vessel or equipment status.

Options. Establishing available approaches toward commercial compliance is efficiently conducted by bounding compliant engine and technology categories. Downselecting narrows the field to representative alternatives with high-success potential.

Cost. Both nonrecurring and recurring costs are estimated by parametric analysis to derive an operating-time cost rate:

1. Qualification
2. Build (non-recurring engineering, additional labor, overhead, and material; equipment validation)
3. Life cycle support

Benefit. Determining regulated emission reductions permits the assessment of MHB. If no change is made to fuel sulfur (fuel is dictated by MilSpec), commercial compliance affects only two criteria pollutants ($PM_{2.5}$ and NO_x) that impact PM MHB. The change in their emissions is calculated according to the vessel's mission-specific operation (load profile, operating hours, brake-specific fuel consumption [bsfc], and fuel properties). At each operating condition emissions are calculated for all installed engine models that have a common load profile and annual operating hours (Eq. 2); the summation of results for each pollutant at all operating conditions provides the annual emissions for that engine set.

$$EF_{eng\,mod,\ opcon} \times n_{eng\,mod} \times P_{opcon} \times T_{eng\,mod,opcon} = E_{vsl,eng\,mod,opcon} \quad (2)$$

Where $EF_{eng\ mod,\ op\ con}$ (g/kW-hr) is the engine model- and operating condition-specific emission factor, $n_{eng\ mod}$ is the number of engines of that model installed, P (kW) is the engine model's power at that operating condition, $T_{eng\ mod,\ op\ con}$ is the engine model's annual operating time at that operating condition, and $E_{vsl,\ eng\ mod,\ op\ con}$ is the emissions from an engine model on a specific vessel at a particular operating condition.
Totaling CY-specific reductions of direct $PM_{2.5}$ and NO_x, multiplied by the pollutant-, source-sector-, and mass-specific MHBPT, yields a pollutant-, source-sector-, and CY-specific operating-time MHB total (Eqs. 3-4).

$$E_{PM_{2.5}} \times MHBPT_{PM_{2.5},\sec,CY} = MHB_{PM_{2.5},\sec,CY,tot} \quad 3)$$

Where $E_{PM2.5}$ (kg) is the mass of reduced $PM_{2.5}$, $MHBPT_{PM2.5\ Sec\ CY}$ (\$CY/kg) is the polutant-, source-sector-, CY-, and mass-specific valuation, and $MHB_{PM2.5\ sec\ CY\ tot}$ (CY\$) is the total monetized health benefit.

$$E_{NO_x} \times MHBPT_{NO_x,\sec,CY} = MHB_{NO_x,\sec,CY,tot} \quad (4)$$

Where the same variable connotation pattern is used as for Eq. 3 The total MHB may be determined for a particular CY (Eq. 5).

$$MHB_{PM_{2.5},\sec,CY,tot} + MHB_{NO_x,\sec,CY,tot} = MHB_{CY,tot} \quad (5)$$

Where $MHB_{CY\ tot}$ (\$CY) is the total MHB for a particular CY resulting from reductions of $PM_{2.5}$ and NO_x.
From the individual $MHB_{CY\ tot}$ values, regression yields operating-time MHB rates. Since EPA's MHBPT valuations are provided for five-year increments, interpolation is used to estimate valuations for each specific intervening year between increments. The results from two mortality risk reduction studies are combined with avoided morbidity valuations to bracket the estimates (EPA 2013, Fann 2012). Each estimate is calculated with both 3% and 7% discount rates to adjust for future year benefits. Thus, two MHB rate ranges are effectively developed for each emission-impacting change in vessel or equipment configuration. Further detail on both bracketing epidemiology studies and discount rates is provided in the "MHB" section of the paper (EPA 2013).

Cost and Benefit Comparison. The value of initial and ongoing commercial compliance costs is facilitated by identifying annual rates over the vessel or equipment useful life, payback period, and ROI. Once all annual total cost and $MHB_{CY\ tot}$ values for newbuild, repower, or retrofit of emission controls have been calculated for the vessel's or equipment's projected useful life, payback period and ROI may be determined graphically or calculated.

Impacts of Other Variables. The more subjectively assessed variables are assessed and discussed:

1. Technology readiness
2. Applicability
3. Acquisition
4. Complexity
5. Compliance strategy
6. Future compliance

Recommendations. Suggested actions are formed on the basis of both quantified cost/benefit and qualitative variable analyses.

The methodology framework is sufficiently flexible to be applied on either a rough order of magnitude (ROM) or a budget level cost basis.

Identify Need

Establish Relevant Requirements, both legislated and implemented, that apply to the vessel or equipment system. For a multiyear acquisition of newbuild vessels or equipment, tabulate the engine application, OEM, model, rated power, cylinder-specific displacement (L/cyl), EPA category, relevant tiers, implementation dates, and regulated pollutant limits.

Current Vessel Status determination requires establishing compliance (collecting certification documents on completed newbuilds or existing equipment in operation) and identifying build specifications through the newbuild period. Certifications and specifications are compared to the relevant regulations pertinent to the already-installed or planned engine installations.

Establish Options

Compliance options fall along a cost and intervention spectrum. The prioritization of compliance technologies proceeds from lowest cost and interference with interfacing systems to higher cost and modification, e.g. upgraded engine model, replacement engine model, and aftermarket emission control systems.

Bounding the compliance options by selecting technology or technological approach bookends, simplifies a consideration of the range of available options. Although, the broad bounding for NSE vessels or equipment necessarily considers NSE engines on one extreme and compliant engines on the other, a hybrid alternative to commercial compliance and NSE status, may yield some of the benefits of commercial compliance for a disproportionate fraction of the cost. Therefore the compliance

option review includes partial or “close-as-practicable-to” commercial compliance measures or technologies (Fig 2).

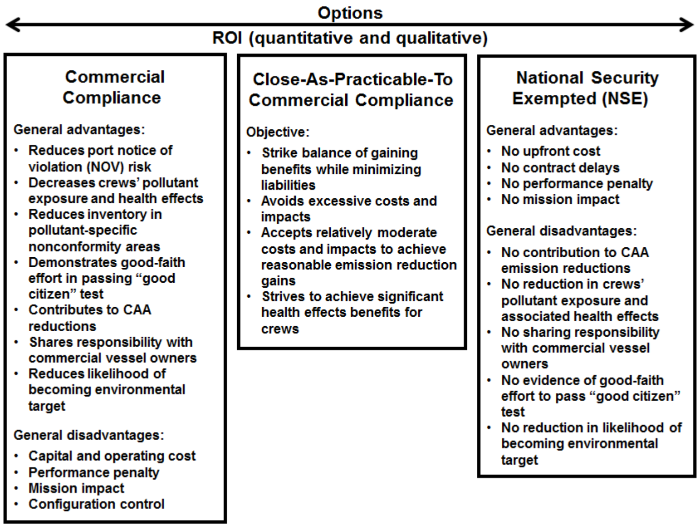

Fig. 2 Commercial compliance vs. NSE: quantitative and qualitative ROI

Fuel use during the vessel or equipment lifetime is a critical factor in this consideration. In particular, extended operation with the worst case fuel is assessed. For emission control, the fuel sulfur limit is likely the primary constraining property. Also, the specified engine oil requires a total base number (TBN) that is tailored to handle fuel sulfur up to that limit. MilSpec oils may not fall within commercial specifications for low ash, sulfur, and phosphorous concentrations. Most catalyzed AT systems are highly sensitive to fuel- and oil-sourced sulfur. In part, this was why EPA mandated ULSD distillate for marine diesel engine use (EPA 2004).

Fuel sulfur and companion engine oils rarely limit in-cylinder emission control technologies, but they may significantly limit AT emission control technologies that can be applied. Therefore, any catalyzed AT or EGR system to attain Tier 4 will need to be sufficiently sulfur tolerant and durable. Durability is an issue because more frequent regenerations and desulfurization events will tend to limit the life of any trap-based technology. Urea-based SCR can be tailored to relative sulfur insensitivity, but requires large onboard volumes of an additional substance (urea) that is difficult to accommodate on many vessels, particularly those designed for national security missions. CDPF or CADPF systems are also broadly characterized by sulfur intolerance, but their calalysts can be tailored to achieve some measure of sulfur tolerance.

Choosing to achieve either engine commercial compliance or opting for an NSE presents distinct quantitative and qualitative advantages and disadvantages (Fig. 2) for vessels. The hybrid alternative to commercial compliance and NSE status can reduce the Service’s or agency’s emissions inventory. By investigating the “close-as-practicable-to” compliance options the resulting benefits may be weighed against the required costs.

Downselecting the bounded options permit several to be candidates to be considered in more depth. The methodology framework’s decision process, illustrated in Fig. 1, is adequately flexible to apply to a newbuild vessel or equipment that may straddle a new emission tier or to a reengined vessel or equipment (including EPA’s remanufacture engine category).

Determine Cost

The proposed methodology framework enables determining costs and benefits of achieving commercial compliance or “close-as-practicable-to” commercial compliance is primarily quantitative. However, those results are considered in the context of the more qualitative topics previously addressed: background for EPA’s regulatory scheme, legislated requirements with implementation dates, commercial compliance technology options, and impacts of other variables. Combining qualitative and quantitative impacts provides sound criteria that may be closely aligned with each organization’s goals, priorities, and budget constraints.

Qualification, in accordance with Navy or other Service requirements, often requires testing that credits service experience and similar design characteristics in engine families.

Build nonrecurring cost categories that encompass compliance options, include the following for a multiyear vessel newbuild period Engineering Change Proposal (ECP) – these categories may also be applied to other new or existing equipment:

Detail design. The shipyard conducts engineering calculations to update three-dimensional computer-aided design drawings. These are converted to two dimensions for use on the shop floor. Then, to estimate cost, the impact to a vessel design is first estimated based on the volumetric change to determine the amount of nonrecurring engineering required. This is validated with comparisons to other ships for similar redesign efforts.

Additional labor. The change to implement any of the options at a particular hull represents a break in the production line which creates a disruption on the standard learning curve. To estimate this, a range should be produced on the learning curve setback. It is then assumed for the Program Life-Cycle Cost Estimate (PLCCE) that the production learning curve is capped after the building of a particular hull number. To account for the production disruption at a future hull number, another range is then created moving the learning curve back several units – to a lead ship not requiring one-time or transitioning costs.

Additional overhead. This cost is accrued as a result of the additional direct labor for the learning setback. A similar ratio of indirect/direct is then applied to the additional work scope.

Additional material. Quotes and/or projected costs are obtained for all the hardware being removed and newly installed. The new hardware cost should then be added to the baseline.

Equipment validation. A notional estimate for OEM validation testing is developed. The cost categories may be estimated on a ROM level, however these are not to be considered for

budgetary purposes. The estimates represent relative cost changes to the program for each technology assessed. Vendor quotes are combined with volumetric and parametric analyses to generate low- and high-end estimates. For the U.S. Navy, data (including Ship Work Breakdown System [SWBS]) or the equivalent is leveraged. A budget-level estimate requires further detailed technical and cost analysis.

Life Cycle Support for commercial compliance or "close-as-practicable-to" commercial compliance options encompass recurring cost categories such as bsfc and possible maintenance.

Quantify Benefit

The methodology framework's quantified variables point toward objective conclusions. Associated assumptions and limitations should be identified.

Environmental Performance benefits are encompassed primarily in quantified emission reductions tempered by fuel penalty. For Navy vessels, both are computed using the on-line, password-accessible Navy marine Engine Fuel Consumption and Emissions Calculator (EFC&EC).

<u>Inputs (conditions)</u> that are required for accurate EFC&EC computations include the following:

1. Annual operating hours (peacetime tempo) and profile;
2. Individual engine load profile;
3. Fuel type and average sulfur level; and
4. OEM unweighted emission rates and bsfc curves (conforming to ISO 8178 test cycles, modes, and weighting [D2 constant speed generating sets with intermittent load or E3 marine applications heavy duty marine engines]) (ISO 1996).

Required inputs to model the operating conditions of a vessel under analysis are presented in Table 3.

Table 3. Inputs and sample data (NOTE: data illustrative only)

Required Sample Vessel Modeling Information	Input Data
Annual underway (UW) operating hrs.	2000 hr
Annual not underway hours (NUW)	NUW hours = 100 for the emergency diesel generator (EDG); all other engines modeled as not operating NUW for zero emissions
Annual hours for auxiliary and boat engines	Boats = 70 hr Fire pump = 50 hr
Propulsion engines UW operating profile (percent of time and corresponding engine power levels)	1. 70% UW time @ loiter speed of 10 knots (kn) 2. 20% UW time in transit @ 20 kn 3. 10% UW time at flank speed of 25 kn
Underway engine operating configuration	1. Two main diesel propulsion engines (MPDEs) 2. One ship service diesel generator (SSDG) 3. Two small boat main engines (SBMPDEs) 4. One fire pump diesel engine (FPDE)
Engine emission factors	Provided by engine OEMs for tier-specific compliance
Engine fuel consumption	Fuel consumption from engine OEMs
SSDG and auxiliary engine power	SSDG @ 50% load (200 kW) SBMPDEs at rated kW EDG @ 80 kW in port FPDE @ 10 kW

Several configurations of engines, representing different levels of engine emission commercial compliance are identified and analyzed. Results from each individually applicable change toward attaining commercial compliance must be identifiable. Applying the following analysis order achieves that objective:

- Establish a baseline for comparison by conducting performance calculations for all engines in a Tier 2 or 3 commercially noncompliant configuration, as would be the case for all engines in an optimal NSE status; and
- Switch each engine application (MPDE, SSDG, EDG, or ship's boat MPDE) to commercial compliance or "close-as-practicable-to" commercial compliance option under consideration, with only one change made at a time.

<u>Outputs (results)</u> from the EFC&EC are computed according to engine tier configuration changes. A separate EFC&EC run is made for each engine configuration change required to achieve a particular engine compliance option. The fuel consumption (FC) (barrels [bbls]/year) and emissions (kg/year) response that corresponds to any emission rate and FC changes is thereby isolated. All other vessel or equipment characteristics are kept constant (operating hours, vessel speed, and fuel type).
Vessel commercial compliance configuration changes could typically include a list of variations similar to the following:

1. MPDEs, SSDGs, EDGs, FPDEs, and SB MPDEs Tier 2;
2. MPDEs changed to Tier 4 (projected), all others Tier 2 [Tier 4 could also apply to SSDGs and EDGs];
3. MPDEs changed to "close-as-practicable-to" Tier 4 (MPDEs with ERADPFs and DOCs), all others Tier 2;
4. SSDGs changed to Tier 3, all others Tier 2;
5. EDGs changed to Tier 3, all others Tier 2;
6. FPDEs changed to Tier 3, all others Tier 2; and
7. SBMPDEs changed to Tier 3, all others Tier 2.

Corresponding emission and FC results for these variations are consolidated and summarized in Table 4.

Table 4. Summary of EFC&EC emission and FC calculations (NOTE: data illustrative only)

Case 1								
Engine	TIER	FC (BBLS)	NOx (kg)	SOx (kg)	CO (kg)	CO2 (kg)	HC (kg)	PM (kg)
MPDE	2	3,907.1	17,985.6	5,865.7	1,762.3	1,856,909	559.6	456.9
SSDG	2	702.2	2,835.5	1,054.0	251.5	333,730	95.2	116.6
EDG	2	12.4	30.0	18.2	7.5	5,916	4.3	3.2
FPDE	2	5.1	9.4	7.5	7.5	2,421	-	2.1
SB MPDE	2	51.8	195.0	78.1	15.0	24,613	9.2	16.0
TOTAL		4,678.6	21,055.5	7,023.5	2,043.7	2,223,589.5	668.3	594.9
Case 2								
Engine	TIER	FC (BBLS)	NOx (kg)	SOx (kg)	CO (kg)	CO2 (kg)	HC (kg)	PM (kg)
MPDE	4	4,266.8	4,358.1	6,160.0	1,760.2	2,014,072	460.1	452.6
SSDG	2	702.2	2,835.5	1,054.0	251.5	333,730	95.2	116.6
EDG	2	12.4	30.0	18.2	7.5	5,916	4.3	3.2
FPDE	2	5.1	9.4	7.5	7.5	2,421	-	2.1
SB MPDE	2	51.8	195.0	78.1	15.0	24,613	9.2	16.0
TOTAL		5,038.3	7,428.0	7,317.7	2,041.6	2,380,752.1	568.8	590.6

Table 4. Summary of EFC&EC emission and FC calculations (NOTE: data illustrative only) [continued]

Engine	TIER	FC (BBLS)	NOx (kg)	SOx (kg)	CO (kg)	CO2 (kg)	HC (kg)	PM (kg)
Case 3								
MPDE	2 + ERADPF + DOC "Close-as-practicable-to" Tier 4	4,024.3	16,906.5	5,865.7	1,762.3	1,856,909	223.8	114.2
SSDG	2	702.2	2,835.5	1,054.0	251.5	333,730	95.2	116.6
EDG	2	12.4	30.0	18.2	7.5	5,916	4.3	3.2
FPDE	2	5.1	9.4	7.5	7.5	2,421	-	2.1
SB MPDE	2	51.8	195.0	78.1	15.0	24,613	9.2	16.0
TOTAL		4,795.8	19,976.4	7,023.5	2,043.7	2,223,589.5	332.5	252.2
Case 4								
MPDE	2	3,907.1	17,985.6	5,865.7	1,762.3	1,856,909	559.6	456.9
SSDG	3	728.9	2,010.5	1,094.6	168.0	346,444	149.8	74.9
EDG	2	12.4	30.0	18.2	7.5	5,916	4.3	3.2
FPDE	2	5.1	9.4	7.5	7.5	2,421	-	2.1
SB MPDE	2	51.8	195.0	78.1	15.0	24,613	9.2	16.0
TOTAL		4,705.3	20,230.6	7,064.1	1,960.2	2,236,303.2	722.8	553.2
Case 5								
MPDE	2	3,907.1	17,985.6	5,865.7	1,762.3	1,856,909	559.6	456.9
SSDG	2	702.2	2,835.5	1,054.0	251.5	333,730	95.2	116.6
EDG	3	10.9	22.5	16.1	6.4	5,202	1.1	1.1
FPDE	2	5.1	9.4	7.5	7.5	2,421	-	2.1
SB MPDE	2	51.8	195.0	78.1	15.0	24,613	9.2	16.0
TOTAL		4,677.1	21,048.1	7,021.3	2,042.6	2,222,875.8	665.1	592.8
Case 6								
MPDE	2	3,907.1	17,985.6	5,865.7	1,762.3	1,856,909	559.6	456.9
SSDG	2	702.2	2,835.5	1,054.0	251.5	333,730	95.2	116.6
EDG	2	12.4	30.0	18.2	7.5	5,916	4.3	3.2
FPDE	3	5.1	8.6	7.5	7.5	2,421	-	-
SB MPDE	2	51.8	195.0	78.1	15.0	24,613	9.2	16.0
TOTAL		4,678.6	21,054.7	7,023.5	2,043.7	2,223,589.5	668.3	592.8
Case 7								
MPDE	2	3,907.1	17,985.6	5,865.7	1,762.3	1,856,909	559.6	456.9
SSDG	2	728.9	2,010.5	1,094.6	168.0	346,444	149.8	74.9
EDG	2	10.9	22.5	16.1	6.4	5,202	1.1	1.1
FPDE	2	5.1	9.4	7.5	7.5	2,421	-	2.1
SB MPDE	3	51.8	157.3	78.1	15.0	24,613	4.3	7.5
TOTAL		4,703.8	20,185.3	7,062.0	1,959.2	2,235,589.5	714.8	542.5

The MPDEs generate by far the largest proportion of emissions and FC. Therefore, altering the tier of the other engines produces a much smaller impact on the overall emissions and FC of the entire vessel.

Monetized Health Benefit (MHB) is used to determine whether the additional cost of a regulated commercially compliant engine or emission control is justified. The PM mass-specific MHBPT concept provides an objective measure of health benefit accrued by pollutant reduction (EPA 2008, EPA 2013, Fann 2012). The value of estimated benefits is related to only emissions of direct $PM_{2.5}$, particulate nitrate and particulate sulfate. Epidemiological study probability data quantifying $PM_{2.5}$ air pollution health effect risk reduction is converted to units of avoided statistical incidences. Through MHBPT, $PM_{2.5}$ and NO_x reductions are valued by quantifying the economic value of associated health impacts avoided in terms of lives saved (avoidance of premature mortality) and reductions in other health impacts (such as visits to the hospital).

EPA's procedure for estimating MHBPT for PM consists of the three steps identified in the introduction to the "Proposed Methodology Framework" section. A further description of each of these steps follows (EPA 2012, EPA 2013):

Estimating source-sector $PM_{2.5}$–related health impacts utilizes Health Impact Assessments (HIAs) to quantify the effect of $PM_{2.5}$ exposure changes on the incidence of adverse health impacts. EPA follows a well-established three-step HIA approach for estimating historical and future health impacts from changes in $PM_{2.5}$ exposure:

1. Develop estimates of sector-specific $PM_{2.5}$ using Comprehensive Air Quality Model with Extensions (CAMx);
2. Determine resultant population exposureusing EPA's benefits assessment tool BenMAP; and
3. Calculate health impacts according to epidemiological-based concentration-response relationships facilitated by health impact functions (Eq. 6 is typical) within BenMAP.

$$\Delta y = y_0 \times (e^{\beta \times \Delta x} - 1) \times Pop \qquad (6)$$

Where y_0 is the baseline incidence rate for the health endpoint being quantified, *Pop* is the population (size and distribution of which were projected to the analysis year) affected by the change in AQ, x is the change in AQ, and β is the effect coefficient drawn from the epidemiological study.

Estimating the economic value of avoided impacts for each source sector follows the quantification of $PM_{2.5}$ exposure-related changes in adverse health impacts. Economic valuation requires a determination of whether the value to individuals for an AQ improvement should be measured as willingness to pay (WTP) or willingness to accept (WTA). WTP is the maximum amount of money an individual would voluntarily pay to gain an improvement and WTA is the minimum amount of money an individual would accept to forego the improvement (EPA 2010). When ambient air pollution is reduced, the risk of future adverse health effects is reduced incrementally for a large population. Since the health effect impact is being assessed before the effect ("ex ante") has occurred, an ex ante WTP economic measure is used to quantify risk. The WTP appropriately measures changes in risk of a health effect, rather than WTP for a health effect that would occur with certainty. However, when considering air pollution reductions, epidemiological studies estimate risk of health effect avoidance. The epidemiological probabilities can be converted to units of avoided statistical incidences if individual WTP for a risk reduction is divided by the observed change in that risk. For example, if the risk of premature mortality is reduced by 1 in 10,000 (0.0001 risk reduction) and the WTP for this reduction is \$100, then the WTP for the avoided statistical mortality amounts to \$1,000,000 (\$100/0.0001). The number of incidences predicted by

epidemiological studies to the relevant population thereby accounts for the size of the affected population (EPA 2012, EPA2013).

Where WTP estimates are not available, such as for hospital visits and admissions, the cost of treating the health effect is used as the primary estimate. However, these treatment costs underestimate the true value of health effect risk reduction because they do not account for the value of avoided pain and suffering (EPA 2013).

Premature mortality accounts for 98% of monetized benefits resulting from PM reduction. EPA argues that value of statistical life (VSL) calculations provide the most reasonable estimate of an individual's willingness to pay for reductions in mortality risk. The VSL approach provides the means to measure small changes in mortality risk experienced by a large number of people (EPA 2012).

Calculating PM MHBPT for contributing pollutants requires the summation of results from multiplying the incidence of adverse health outcomes by the economic value of those outcomes and dividing by the associated sector emissions. EPA's PM National Ambient Air Quality Standards (NAAQS) RIA provides a more in-depth description of this step (EPA 2012).

MHBPT estimates used for this methodology framework are significantly underestimated because of the following analysis shortcomings and/or data gaps (EPA 2012, 2013):

1. For assessments with operation continuing beyond 2030, MHBPT NO_x and PM benefit-per-ton values (significantly increasing from 2015-2030) for years exceeding 2030 must utilize 2030 MHB values for lack of analysis rigor applied to extrapolated values.
2. No MHB values exists for ozone, SO_2, and NO_2 reductions. All three components are associated with adverse respiratory health effects and suggest premature mortality.
3. Volatile organic compound (VOC) organic carbon aerosol contribution to PM also cannot yet be quantified without unacceptable uncertainty.
4. For vessels under analysis only peacetime vessel operational tempo is considered.
5. The health benefits accrued by vessel or equipment crews operating in close proximity to the exhaust plume and sometimes constricted under-ventilated spaces will generally experience a much more significant impact of adverse health effects.

For the high and low MHBPT estimates described in the "Benefits" section of the paper, EPA also applies high and low values associated with 3% and 7% discount rates, respectively. Although the health-benefits-per-ton values represent the per-ton annual benefit that occurs in the year in which those values are applied, EPA assumes a mortality "cessation" lag when valuing the reductions in mortality risk. Mortality risk is not realized immediately (in the year of reductions), but is distributed over a number of future years. Therefore, to reflect the time value of money, EPA uses the 3% and 7% discount rates to discount the benefits that are projected to occur in years beyond the year of the reductions. A 3% discount reflects reliance on a "social rate of time preference" discounting concept. A 7% rate is consistent with an "opportunity cost of capital" concept to reflect the time value of resources directed to meet regulatory requirements (EPA 2012). EPA's Science Advisory Board Health Effect Subcommittee (SAB-HES) advised the use of a segmented lag structure characterized by 30% of mortality reductions in the first year, 50% over years 2 to 5, and 20% over years 6 to 20 after the pollutant reductions. The 3% and 7% discount rates do not change the total number of estimated deaths, but the timing of those deaths (EPA, 2013, (Davidson, pers. com.).

EPA summarizes the primary assumptions of its analysis as follows (EPA, 2012):

1. All fine particles, regardless of their chemical composition, are equally potent in causing premature mortality. Further differentiation of effect estimates according to particle type cannot yet be substantiated.
2. Health impact functions based on national studies are representative for exposures and populations in California (CA).
3. The health impact function for fine particles is log-linear without a threshold. The estimates include health benefits from reducing $PM_{2.5}$ in areas with varied concentrations, both those that are in nonattainment and those in attainment.
4. A cessation lag exists between the change in PM exposures and the total realization of changes in mortality effects.
5. To characterize the uncertainty in the relationship between $PM_{2.5}$ and premature mortality (accounting for over 98% of total monetized benefits), twelve estimates were included based on results of an expert elicitation study.

In addition to these assumptions there are many uncertainties inherent in EPA's analyses (EPA, 2012). Estimated parameters and inputs from many data sources and models were utilized in this complex analysis process and there are subsequently many sources of uncertainty. When the uncertainties from each analysis stage are compounded, even small uncertainties can have large effects on the total quantified benefits. Nevertheless, after reviewing the EPA's approach, the National Research Council (from the National Academies of Science), concluded that EPA's general methodology for calculating the benefits of reducing air pollution is reasonable and informative in spite of inherent uncertainties (EPA 2012).

Relate Cost and Benefit

Options to achieve commercial compliance or "close-as-practicable-to" commercial compliance are bounded and downselected based on potential; costs are assessed according to qualification, build, and life cycle support; and environmental performance is determined. Benefits are then quantified according to MHB and compared to the established costs.

Calculate Annual Rates Over Equipment Useful Life based on a particular year's dollar value (e.g. dollars for calendar year 2015 [$CY15]) and applying an average inflation rate (e.g. averaged rate of last ten years) to project future costs. When the inflation-adjusted $CY cost averages are added to lifetime fuel penalty and other additional life cycle support costs, total estimated lifetime cost for the technology insertion or modification is determined. Fuel cost is based on that provided by the Defense Logistics Agency (DLA) (DLA 2015). Thirty years is assumed for vessel useful life.

Emission reductions achieved by the installation of more

stringently regulated commercially compliant engines and/or the application of emission controls are calculated (refer to the earlier "Environmental Performance" section) using the EFC&EC and based on ISO 8178 cycle mode emissions data, annual operating hours, and operating profile. FC impacts are similarly determined from ISO 8178 cycle mode bsfc data. The magnitude of certain emission constituents and fuel consumption is dependent on fuel type and fuel properties, including sulfur content.

Calculate Payback Period Range ($CY) by identifying the year at which the cost (nonrecurring and recurring) and benefit trend lines intersect. Payback periods for commercially compliant SSDGs and EDGs are illustrated in Figs. 3 and 4 for a sample newbuild vessel with an assumed 30-year useful life.

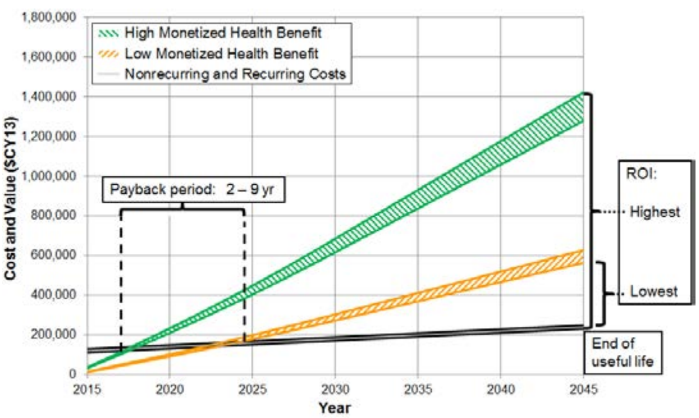

Fig. 3 Emission control cost/benefit example: replace Tier 2 SSDGs with Tier 3 SSDGs (NOTE: data illustrative only)

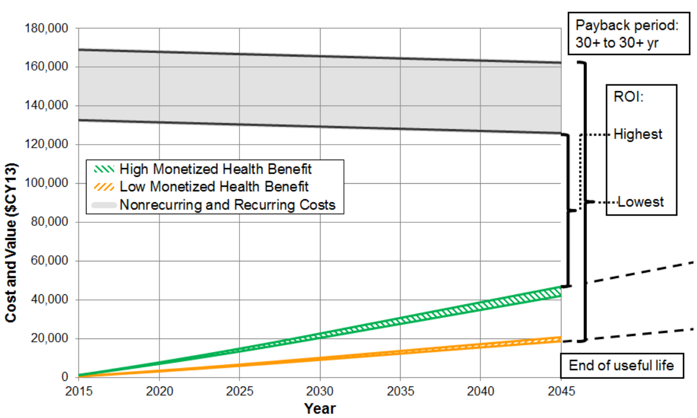

Fig. 4 Emission control cost/benefit: replace Tier 2 EDGs with Tier 3 EDGs (NOTE: data illustrative only)

The MHB low and high benchmark estimates, provide benefit valuation reference points and bound the expert elicitation stud estimates mentioned in the "MHB" section. When selecting a benefit per ton estimate for use with a source sector not specifically modeled, it is necessary to determine which composite sector is the best match with respect to the source characteristics that would affect the level of benefits. The cost of vessel or other equipment newbuild period emission control changes may then be assessed based on that benefit. Both cost and benefit pertain to engine model or emission control changes required to acquire and/or maintain commercial compliance or close-to-commercial compliance.

Calculate ROI Range ($CY) by determining return on investment (ROI) values (illustrated in Figs. 3 and 4). ROI is the difference between the highest and lowest MHB rate and cost rate, at the projected end of the vessel's useful life. Table 5 provides a summary of primary inputs and outputs of the application of this methodology framework for the Figs. 3 and 4 examples. The data provided is selective because of its sensitive nature. MPDEs are also included in the table under the "'Close-As-Practicable-To' Commercial Compliance" section. For this illustrative vessel, no engine model in commercial compliance was available to replace the NSE MPDEs, so one AT option (Tier 2 engine with ERADPF and DOC) was considered to achieve "close-as-practicable-to" commercial compliance. Highlighting (green, yellow, or red) was applied to indicate favorability and acceptability (refer to the Table 5 legend).

Table 5. Commercial compliance cost/benefit analysis summary example: replacement of SSDGs and EDGs; and modification of MPDEs (NOTE: selective data illustrative only)

Commercial Emissions Compliance: Modifications to Newbuild Vessel Engine Models

Application	OEM	Model	Commercial Compliance Standard		EPA Regulated Emission Limits for Commercial Compliance (g/kW-hr)					Monetized Health Benefit from Modifications Required for Commercial Compliance ($K)	Life-Cycle Costs for Compliance Modifications			ROI ($K)	Payback Period (yrs)	Commercial Compliance Implementation Complexity (high/med/low)	Notes
			Tier	Date	NOx	NOx + HC	PM	HC	CO		Non-recurring ($K)	Recurring ($K)	Total ($K)				
SSDG			2	2004	N/App	7.2	0.20	N/App	5.0					320 - 1,200	2 - 9	Low	Upgraded engine
			3	2014	N/App	5.6	0.11	N/App	5.0								
EDG			2	2004	N/App	7.2	0.30	N/App	5.0					(140) - (79)	30+ - 30+	Medium	Larger engine
			3	2013	N/App	5.4	0.12	N/App	5.0								

*NOTE: No return on investment (ROI) or payback period within assumed 30-year life-cycle of vessel

"Close-As-Practicable-To" Commercial Compliance: Modification to MPDE Exhaust Systems

Application	OEM	Model	Commercial Compliance Standard		EPA Regulated Emission Limits for Commercial Compliance (g/kW-hr)					Monetized Health Benefit from Modifications Required for Commercial Compliance ($)	Life-Cycle Costs for Compliance Modifications			ROI ($)	Payback Period (yrs)	Commercial Compliance Implementation Complexity (high/med/low)	Notes
			Tier	Date	NOx	NOx + HC	PM	HC	CO		Non-recurring ($)	Recurring ($)	Total ($)				
MPDE			2	2007	N/App	7.2	0.20	N/App	5.0								
			4	2016	1.8	N/App	0.06	0.19	5.0								
Partial Compliance Option					Estimated Emission Levels Attainable												
MPDE with ERADPF & DOC																	

Legend -- Cell Highlighting for ROI, Payback Period, Implementation
High favorability
Acceptable
Low favorability

Assess Impacts of Other Variables

No quantitative methodology can satisfactorily assess all qualitative aspects and variables. Each qualitative variable is addressed, discussed, and documented.

Technology Readiness is critical to successful insertion and can be assessed by considering level of development (COTS or EOTS) and commercial market acceptance. Readiness for the field is relevant only to aftermarket emission control technology considered for "close-as-practicable-to" commercial compliance. Commercially compliant engines have achieved satisfactory commercial readiness by virtue of the regulatory certification process. Some aftermarket technologies have also been similarly certified by EPA or CARB. For noncertified aftermarket emission control technologies, market readiness is determined according to production status, fielded units, and

experience. Limited broad market surveys are conducted for the investigation in order to define the most applicable and highest-potential emission control systems that could enable commercial compliance.

Applicability of technology for U.S. Navy NSE vessels or equipment use requires the additional elements of sufficient sulfur tolerance for fuels (MilSpec and MGO for vessels); adequate performance, reliability, and durability to meet the operational requirements; and a proven marine environment track record.

Commercial compliance measures are checked to ensure the vessel can meet all intact and damage stability (center of gravity [CG] and sea-keeping) criteria by any reduction in the Service Life Margin (SLM). The SLM accommodates the anticipated weight growth during the vessel's service life without compromising hull strength, reserve buoyancy, and stability. An SLM reduction may moderately constrain weight additions during the useful life of the vessel.

Similarly, any additional electric power requirements are checked to ensure vessel load accommodation. Also, impacts on bsfc need to be acceptable from a vessel range and operating cost standpoint (reference recurring costs in Table 5).

Acquisition costs are detailed in the "Determine Cost" section. Adopting the NSE approach produces unique procurement challenges. U.S. OEMs continue to manufacture a certain proportion of noncompliant engine models for the developing world where regulations are fewer or less stringent. However, OEMs expend little effort or expense to incorporate the latest technological advances, as production improvements, in those noncompliant engine models. In addition, OEMs typically move the manufacturing of noncompliant models offshore. There is a national security drawback inherent in spare engine and parts availability from less secure low-labor-cost areas to which production has been moved.

Complexity is assessed according to additional controls, fluids, interfacing systems, monitoring, and maintenance. Requirements for engine integration and associated engine development are carefully investigated. Similar qualitative aspects of each study should be discussed thoroughly in the "Establish Options" and "Determine Cost" sections of the study, as well as the discussion of results and recommendations.

Compliance Strategy includes the broader impacts of the disadvantageous items forfeited when adopting NSE vessel status (Fig. 2):

1. No contribution to CAA emission reductions;
2. No reduction in crews' pollutant exposure and associated health effects;
3. No sharing responsibility with commercial vessel owners;
4. No evidence of good-faith effort to pass "good citizen" test; and
5. No reduction in likelihood of becoming an environmental target.

Implementing measures to keep in step with the commercial world contributes to the EPA goal of an ongoing reduction in the marine transportation sector's contribution to the national inventory. However, when military services and security agencies unnecessarily using the NSE works against advancing toward that goal. The contribution to the national emissions inventory by the Services and agencies responsible for national security will be increasingly disproportionate to their Fleet cumulative kW/hours as more commercially noncompliant NSE engines are fielded.

It is advantageous for these organizations to not experience significant growth of their emissions relative to the commercial sector, especially if that means relying on commercially noncompliant engines. The increasing off-shore production of those engines will limit parts availability during wartime.

Future Compliance is a consideration if commercial compliance is to be maintained through a vessel class newbuild or new equipment production period. Future regulation tiers should be met by new engine models that are certified to the in-force tier and subsequently installed on each new vessel. Engine advance purchases are unacceptable, if not in line with industry or shipyard-specific practice (Thomas, pers. com.). EPA intends to prevent the circumvention of more stringent emission regulations. In marine applications, circumvention is attractive to the shipbuilder to reduce acquisition cost, rework to accommodate a new engine model, and operational cost.

RESULTS AND DISCUSSION

In this paper, no single vessel was selected as a case study to illustrate the application of the proposed methodology framework. Nevertheless, several observations can be made from the illustrative data presented.

Methodology Framework Application

The process and categories of the proposed standardized methodology framework, are effective in achieving an objective assessment of the costs and benefits of procuring commercially compliant engines for NSE vessels or equipment. The methodology framework is equally applicable to assessing emission control technologies to achieve "close-as-practicable-to" commercial compliance.

Need for a particular vessel or equipment is identified according to current applicable EPA regulations. Compliance throughout the newbuild period is considered. Later-built vessels might straddle currently legislated, but not yet implemented regulations. Vessel reengining or engine overhauls provide opportunities to achieve emission reductions cost effectively.

Options are established by a broad consideration of commercial compliance options and partial or "close-as-practicable-to" commercial compliance measures. This approach objectively bounds the compliance options toward an objective of cost-effective emission reductions.

Using the rationale in the "Quantify Benefit" section, a "close-as-practicable-to" Tier 4 aftermarket ERADPF and DOC is considered for the illustrative MPDE. A Tier 4 PM level is targeted by changing out the ship silencer with this AT system.

Cost is categorized according to qualification, build, and life cycle support requirements. Determination of these costs is conducted according to a parametric approach based on inputs from engine OEMs, aftermarket emission control vendors and regulatory certification data, equipment experts and planners, and shipyards.
Tier 3 FC may be less than Tier 2 for some engines, however for most engines there is a fuel penalty when moving from a Tier 2 to Tier 3 or 4 engine. This is a factor in the annual cost rate.

Benefit is quantified according to environmental performance and MHB.
As explained in the "MHB" section of the paper, the MHB rate addresses only the health effects value of NO_x and PM reductions, with no value growth after 2030. NO_x and PM MHBs are multiplied by the EFC&EC-generated FC and emission results summarized in Table 4.

Cost and Benefit may be related after determining annual rates over the useful life, payback period, and ROI.
Cost and benefit ranges are presented graphically in Figs. 3 and 4. From this illustrative example, the resulting payback periods are derived by determining the time (yr) intersection of nonrecurring and recurring cost rate with the MHB rates and subtracting the time (yr) of entry into service. EPA uses low and high estimates with each having an associated discount rate range. ROIs (difference between MHB rates and cost rates, each at the end of the vessel useful life) are also indicated. The payback periods and ROI ranges provided in Table 5 and Figs. 3 and 4 indicate the lowest and highest payback period intersection points and end-of-life ROI values.
The 2-9 year payback period and positive ROIs in Fig. 3 are clearly favorable, whereas no payback period in the assumed 30-year useful life and negative ROIs in Fig. 4 are clearly unfavorable. The, Tier 3 SSDG replacement to the Tier 2 SSDG is attractive and compelling from a cost and benefit standpoint, while the Tier 3 EDG replacement to the Tier 2 EDG is unattractive, based on this cost-benefit analysis. The EDG replacement is not compelling because of the low number of annual operating hours (100 hrs. in this illustrative example [Table 3]). In terms of emission reduction and fuel penalty impact, the MPDEs largely overshadow that of the other shipboard engines. Neither the commercially compliant SSDG or EDG results and conclusions are trivial. Therefore, the value of the MHB-based methodology framework is substantiated. Validation of these results would lend credence to this analysis and could be achieved by shipyard and operational cost accounting and one (baseline test) or more (6-month degradation test and/or a late life test) shipboard emissions tests.

Other variable impacts are also evaluated and documented, particularly those that are primarily subjective in nature.
Although the cost and benefit annual rates might indicate a favorable basis for recommending a commercial compliant engine model or applying a "close-as-practicable-to" commercial compliance emission control, many other variables might indicate overall low favorability. Variables in that category might include those presenting insurmountable obstacles such as vessel range, engine room space, SLM, additional electric power, etc.

Recommendations are developed on the basis of both quantified and qualitative results, identifying assumptions and limitations, and providing adequate explanation

CONCLUSIONS
This paper promotes a standardized methodology framework for assessing costs and benefits of selecting commercially compliant engines for NSE vessels. The approach is equally applicable to any mobile and stationary equipment meeting the NSE criteria. Both engines in commercial compliance and emission controls to achieve "close-as-practicable-to" commercial compliance are considered. The strengths of the methodology framework, include its objectivity, relative ease of determination, and basis – that of the conventional and widely accepted EPA RIA MHB. However, there are qualitative elements that cannot be easily incorporated in the quantitative core of this approach. These must be carefully discussed and documented, and weighed against the quantitative results.

RECOMMENDATIONS
A formal, more-defined procedure should be developed according to this primarily conceptual methodology framework and applied to a number of vessels or other equipment, including those that are newbuilds and reengined (including EPA's "remanufacture" engine category).
Studies and actual application of study findings should be monitored and evaluated.
The methodology should be refined in accuracy from its current framework status. A lower-level ROM screening methodology could complement a higher-level budget-level procedure. Both should be developed, validated, and applied on a trial basis.

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